

ELECTRONIC HOLOGRAPHIC NDE

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INTRODUCTION

The capabilities of holographic NDE to detect unbonded and delaminated defects within bonded, laminated and composite structures has been previously demonstrated [1]. However, this NDE method has historically not been as readily accepted by industry as other NDE methods. This was primarily due to the relatively long time and high cost required per part inspected and the high level of expertise required of the operator. A holographic NDE method was developed [2,3] that significantly reduces the inspection time and the required level of operator expertise making this method both practical and cost effective for production applications. Recently, an electronic imaging system [4,5] has been incorporated to replace the photographic film process used previously. With this latest improvement, the current holographic NDE system offers several benefits over other NDE methods. Holography provides a large field of view which permits an area up to several square feet to be inspected with one hologram. The inspection rate is also extremely fast. Since the electronic system operates at 30 frames per second, the easily interpreted inspection results are viewed in real time. The method can detect "touching" unbonds and delaminations since, as will be discussed later, the bond line(s) are stressed as part of the inspection procedure. With the electronic imaging, a holographic inspection may be performed with very little involvement of an operator who may possess little actual knowledge of holography.

HOLOGRAPHIC NDE METHOD

A typical holography system is shown diagrammatically in Figure 1. The output of the laser is split into an object beam that illuminates the structure to be inspected and a reference beam that illuminates the holographic film. In both beams, a spatial filter, that consists of a microscope object and pinhole, diverges the laser beam and removes any spatial noise. The film used to record the holographic images has historically been 35mm film and 2 inch square or 4 inch by 5 inch glass plates with a silver halide emulsion that requires processing with chemicals. More recently, cameras have been available that use thermoplastic film in the form of a 1 inch square reusable plate.

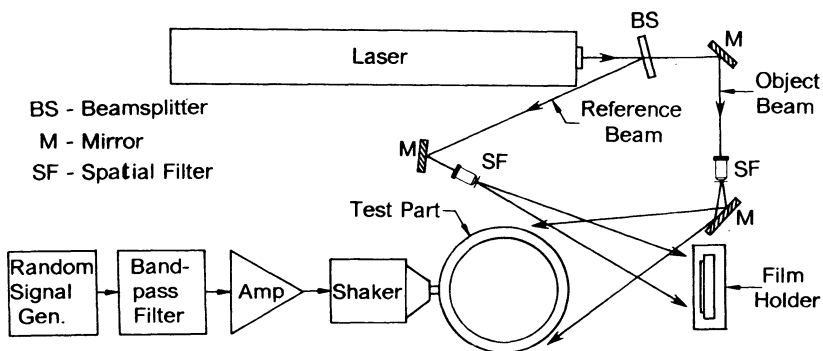


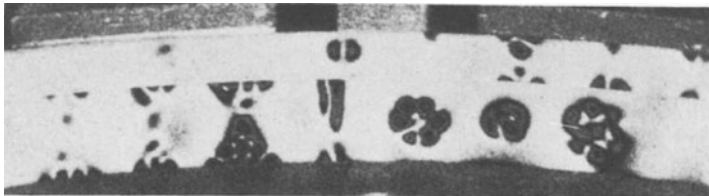
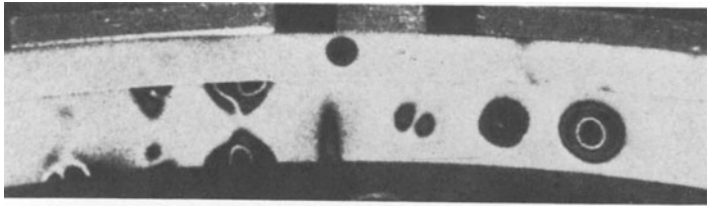
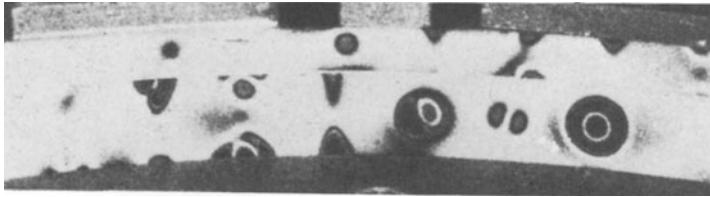
Figure 1 Holographic NDE system with random vibration excitation of test part.

Since holography senses deformation at the surface of the structure, this NDE method requires stressing the bond line(s) within the structure during the inspection process. This may be accomplished using either vibration excitation, pressure (vacuum), or temperature. The best stressing method will depend on the material and configuration of the structure. A defect must sufficiently weaken the structure and the bond line adequately stressed to cause the surface of the structure to deform before the flaw will be detected. However, the amount of deformation required is very small since holography can detect deformations of less than a micron (4×10^{-5} in). If vibration stressing is used, a time average hologram is taken while the structure is excited. For pressure and temperature stressing, double exposure holography is required. The film is exposed once with the structure at one pressure or temperature and again at a different pressure or temperature. The resultant fringes on the time average or double exposure holograms are proportional to the surface deformation of the structure due to the dynamic or steady state load. Flaws in the structure are identified as areas of high deformation or anomalies in the fringe shapes.

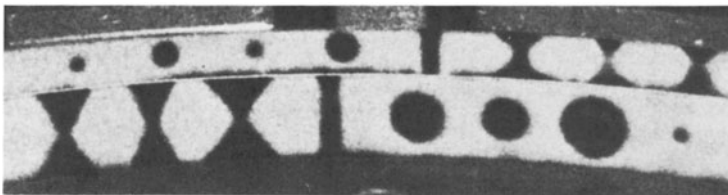
For some bonded, coated, or composite structures, holographic NDE with vibration stressing has been demonstrated to accurately detect unbonds and delaminations. Historically, however, this method has been time consuming and required a highly skilled operator since the frequency of the sinusoidal excitation had to be tuned properly to excite defects of different sizes and a hologram taken at each frequency. Also, the accuracy of this technique was only as good as the operator and could vary from operator to operator. The new technique developed at Pratt & Whitney that uses random vibration excitation eliminates these problems. Since defects of all sizes are excited simultaneously, only one hologram is taken, as shown in Figure 2, and since the operator does not have to tune the frequency, repeatable, accurate results are obtainable with little operator involvement. The time required to inspect a part is significantly reduced from several hours to a matter of minutes. The excitation system is shown in Figure 1. The test part is excited by a piezoelectric crystal shaker attached to the part or to a test fixture. The random excitation signal is generated by a white noise function generator, filtered to the desired frequency range by a variable bandpass filter, and amplified to provide the shaker drive signal. A high frequency accelerometer



(a)



(b)



(c)

Figure 2 Holographic NDE test master showing (a) programmed defects, (b) results using sinusoidal excitation at various frequencies and (c) results using random excitation.

and associated readout system monitors the shaker output. The actual frequency range and amplitude of the random vibratory excitation to give optimum results will depend on the configuration of the part to be inspected. Typically, a frequency range of 20 to 60 KHZ has been used. However, for the test piece that has little structural damping, a higher minimum frequency may be required to not excite any significant structural resonances. A highly damped structure will require lower frequency excitation to transfer sufficient energy into the structure to detect any flaws. The amplitude of the excitation is

highest level that still excites the structure in areas with no defects to a displacement below the sensitivity of the hologram. A test master with intentional programmed defects is helpful in establishing the optimum frequency and amplitude of the random excitation.

Typical inspection results on a sampling of the types of structures on which holographic NDE is currently utilized to detect unbonds and delaminations are shown in Figures 3 through 5. A portion of a gas turbine engine honeycomb duct consisting of a 0.250 inch cell size honeycomb core bonded between two 0.030 inch thick face sheets is shown in Figure 3. An unbonded area is indicated and even the individual honeycomb cells can be seen. A graphite/polyimide composite engine nozzle flap is shown in Figure 4. Several indications of internal delaminations are easily visualized. The results shown in Figures 3 and 4 were accomplished using random vibration excitation. An aft closure of the Space Shuttle's booster separation motor is shown in Figure 5a. A layer of insulation is applied to the motor case to insulate the case from the solid rocket fuel. In Figure 5b, the holographic NDE results on a closure from a fired motor is shown. The closure was placed in a vacuum chamber and a double exposure hologram was taken at atmospheric pressure and at a vacuum of 7 inches of mercury. Unbond indications are shown as areas of high fringe density.

ELECTRONIC HOLOGRAPHY SYSTEM

To make the holographic NDE system easier and faster to operate, enhance the method for additional automation, and make the method more attractive for production applications, an electronic imaging system has been developed. This system allows holographic images to be recorded totally without the use of film. The holographic NDE system with electronic imaging is shown in Figure 6 and diagrammatically in Figure 7. Image-plane holograms are imaged by a speckle interferometer, shown in Figure 8, and a TV camera mounted to the interferometer. The interferometer consists of a mirror to direct light from

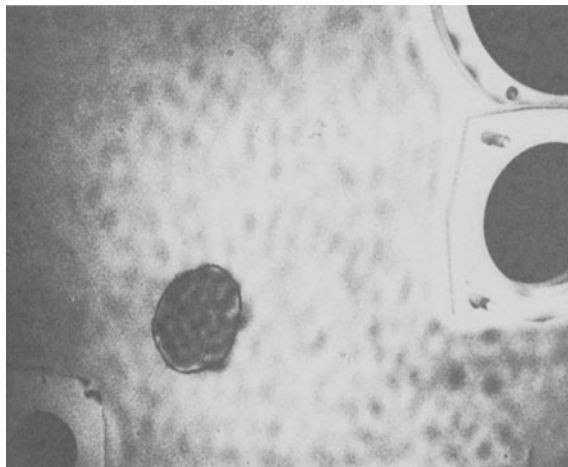


Figure 3 Holographic NDE results on portion of honeycomb duct showing indication of unbond between honeycomb core and face sheet.

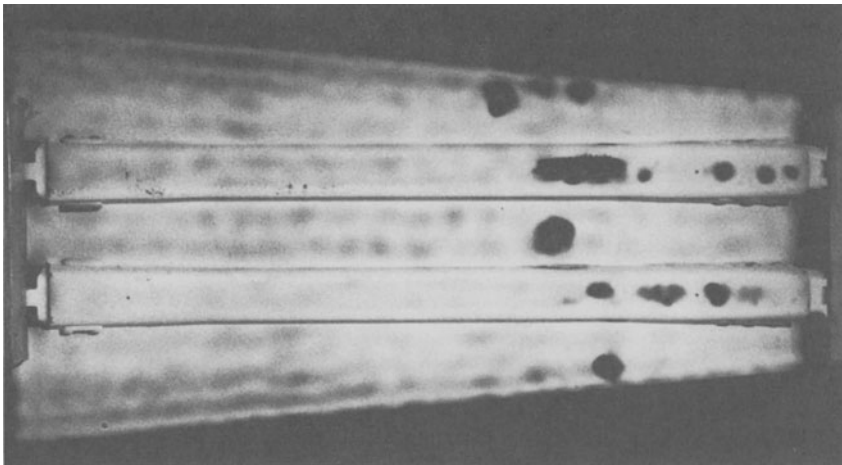


Figure 4 Holographic NDE results on composite nozzle flap showing delamination indications (dark areas).



(a)



(b)

Figure 5 (a) Space Shuttle booster separation motor aft closure and (b) holographic NDE results of a fired motor showing unbond indications.

the object, an aperture, a lens, and a 90% reflecting dielectric beam-splitter. The lens is adjusted, while viewing the monitor, until the object is in focus. The TV camera is a charge coupled device (CCD) with a 512 (horizontal) by 492 (vertical) pixel array.

The output of the CCD camera is fed to a pipe-line image processor. The output image viewed on the monitor is derived from four successive TV image frames. Between each of these four frames, the phase of the reference beam is shifted 90° by the phase stepper mirror. A hard copy of the output image may be made on a video

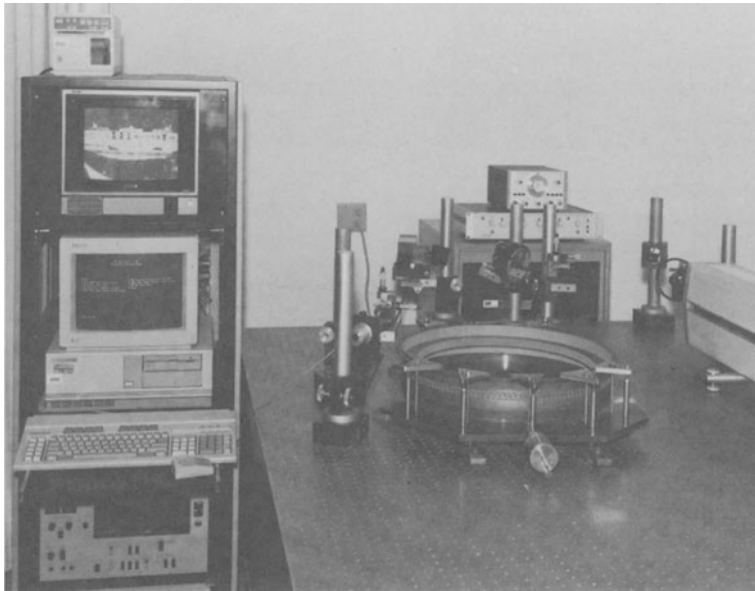


Figure 6 Electronic holographic NDE system.

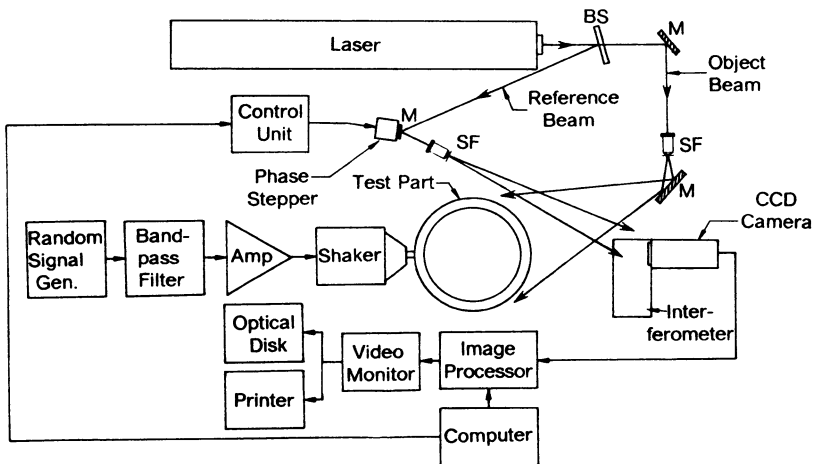


Figure 7 Electronic holographic NDE system with random vibration excitation of test part.

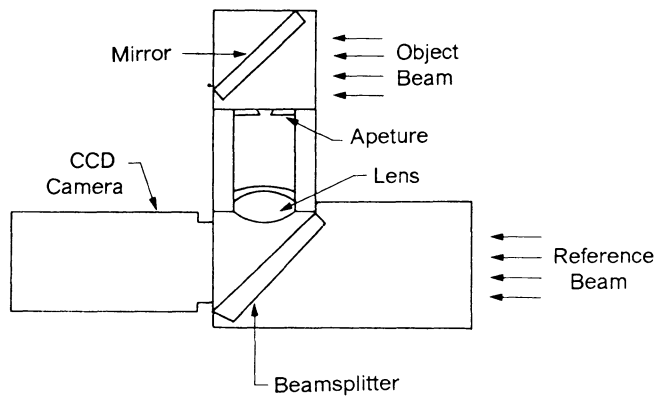


Figure 8 Speckle interferometer used in electronic holographic NDE system.

printer or stored on an optical disk. A single 5 1/4 inch rewritable optical disk provides 1G byte of storage which will accommodate 3500 holographic images. The overall system operation is controlled by a computer.

The electronic imaging system makes possible the viewing of the inspection results in real time saving considerable time over conventional film imaging systems and totally eliminates the use of expensive film and messy processing chemicals. The system is capable of both time average and double exposure holograms. It has a frame averaging mode that can average 2, 4, 8, or 16 output frames for flicker suppression and a speckle averaging mode which averages four output images with differing illuminations of the test part to remove black speckles from the image. The resultant image approaches, if not equals, the image quality obtainable with film. Other features include color enhancement which highlights only actual defects in color, titles and labels may be added to video image, and size of defects may be measured on the monitor screen using calipers movable with a mouse or the keyboard. Typical holographic images obtained using the electronic imaging system are shown in Figures 9 and 10.

SUMMARY

Since holography measures surface deflection, if the defect is deep within a thick structure or if the defect is extremely small, holographic NDE may not detect the flaw. However, defects as small as 0.100 inch have been routinely detected.

Electronic holographic NDE has been demonstrated to be a powerful tool for detecting unbonds and delaminations in bonded, coated, and composite structures. The method is fast and cost effective, has a large field of view, and can accurately detect "touching" unbonds and delaminations. Holographic NDE systems have also been highly automated for high volume, production applications.

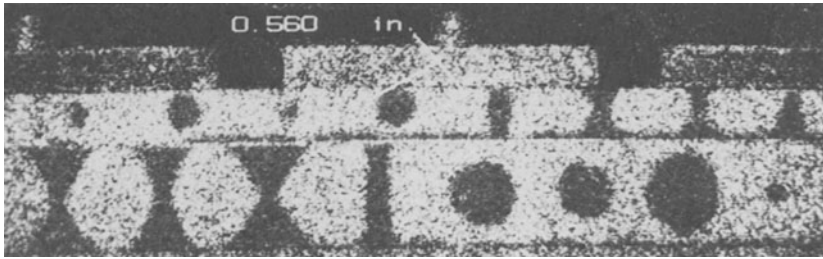


Figure 9 Electronic holographic NDE results on test master with programmed defects.



Figure 10 Electronic holographic NDE results on gas turbine engine composite fan blade showing delamination indications (dark areas).

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